Nuclear Instruments and Methods in Physics Research B 331 (2014) 187–190

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Copper ion implantation of polycarbonate matrices: Morphological and structural properties

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ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 19 November 2013
Accepted 20 November 2013
Available online 3 February 2014

Keywords:
Ion implantation
Polymers
Noble metals
Carbonization process
AFM
XRD

ABSTRACT

The implantation of 1 MeV $^{63}Cu^{+}$ ions in polycarbonate (PC) matrices has been carried out in order to evaluate the morphological and structural modifications induced in the polymer as a function of the ion fluence in the range 5×10^{13} ions cm^{-2} to 1×10^{17} ions cm^{-2}. Atomic Force Microscopy analysis reveals a significant roughness increase of the polymer surface only for fluences higher than 5×10^{16} ions cm^{-2} with the presence of hillock structures which surface density increases with increasing the ion fluence. X-ray Diffraction measurements of PC implanted with fluences in the range between 5×10^{15} at cm^{-2} and 5×10^{16} at cm^{-2} reveal an increase of the disorder inside the PC matrix, as a consequence of the damaging process induced by the ion irradiation. Evidences about the presence of exotic phase structures ascribed to both cubic Cu_2O and cubic Cu have been found.

1. Introduction

The modifications induced in the physico-chemical properties of ion beam irradiated polycarbonate (PC) matrices depend on the experimental parameters as ion energy, fluence and nature of the implanted species [1–3]. Ion irradiation of PC in the range between keV and MeV induces changes of the chemical structure and of the physical properties of the matrix mostly due to the formation of carbon clusters arising from the polymer carbonization [1]. Nevertheless, depending on the incident energy, also the implanted ions tend to aggregate due to their strong cohesive energy giving rise to nanostructures when the supersaturation threshold is overcome [4]. In particular, the increase of the linear and non-linear refractive index increase of the polymers allows producing waveguiding and grating structures highly promising in optoelectronics and integrated optics [5]. As well as, the surface/volume resistance reduction ensure that still flexible and conducting plastics can be obtained for electrical bio-sensing [6], and strain sensing applications [7,8]. The main reason of such novel behaviors lies in the creation of both a carbonaceous cluster network arising from native species [9], and/or of the metal-based nanostructures when metal ions are implanted [7].

In the interaction between 1 MeV $^{63}Cu^{+}$ and PC, the damages related to inelastic collisions, arising from electronic energy losses, do not completely dominate those ones due to elastic collisions (from nuclear energy losses) [1,2]. Under these conditions, the carbonization process do not completely overwhelm the aggregation of metal implanted ions, thus improving the optical and electrical response of polymers due to both the production of carbon cluster from the matrix and the metal-based clusters from arriving species. Indeed, in our previous works evidences of the possible presence of metal exotic clusters were found in PC matrices irradiated with 1 MeV noble metal ions, together with the chemical modifications observed inside the polymer. The creation of chemical defects and the subsequent density fluctuations in polymer films under ion irradiation has been associated to carbonaceous cluster formation whose size mostly grows after the ion tracks start overlapping. In this respect, a buckminsterfullerene structure based on $C_{60,}$ or, more generally, C_{x0} rings it is assumed to be more probable than a hexagonal one [10].

In the present work the effects related to the implantation of 1 MeV $^{63}Cu^{+}$ in PC matrices with fluences in the range between 5×10^{13} ions cm^{-2} to 1×10^{17} ions cm^{-2} are studied in terms of the surface and structural modification of the matrix. The study is devoted to identify ion fluence values suitable to achieve the nucleation of metal clusters from the implanted species, without compromising the overall bulk morphology of the polymer ascribable to the amount and the nature of the changes induced by the carbonization process.

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http://dx.doi.org/10.1016/j.nimb.2013.11.033

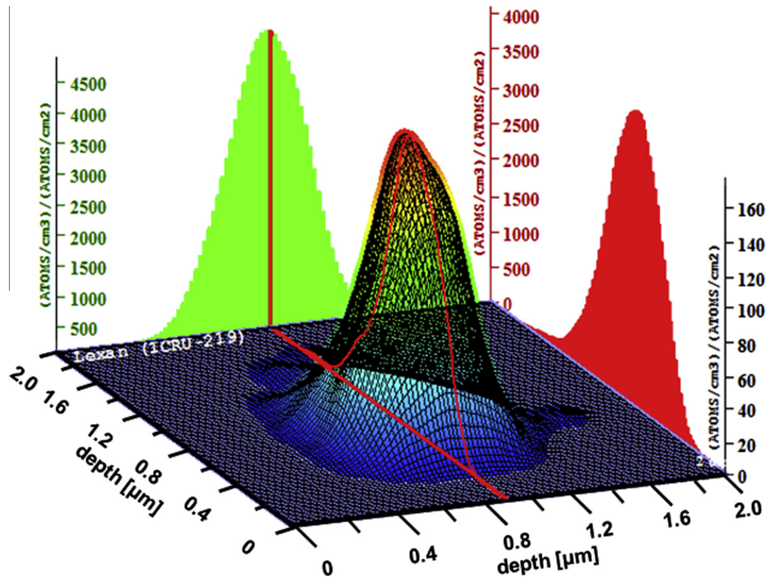

Fig. 1. Simulation, with SRIM 2013 software [15], for 1 MeV $^{63}Cu^{+}$ irradiation of PC, showing that the ion distribution inside the matrix is characterized by a projected range of 1.2 µm and a straggling of ~200 nm.

2. Experimental

PC matrices (Makrofol-KG, $C_{16}H_{14}O_3$, is an aromatic polymer with density of 1.2 g cm^{-3}, derived from Makrolon GP resin, by Bayer AG) [11] with a thickness of 1 mm, were irradiated with 1 MeV $^{63}Cu^{+}$ ions by means of a 3 MV 4130HC Tandetron accelerator (High Voltage Engineering Europa B.V.) at CEDAD – CEnter for DAting and Diagnostics of the Department of Engineering for Innovation, University of Salento [12–14]. The ion implantation was carried out with a current density of 40 nA cm^{-2}

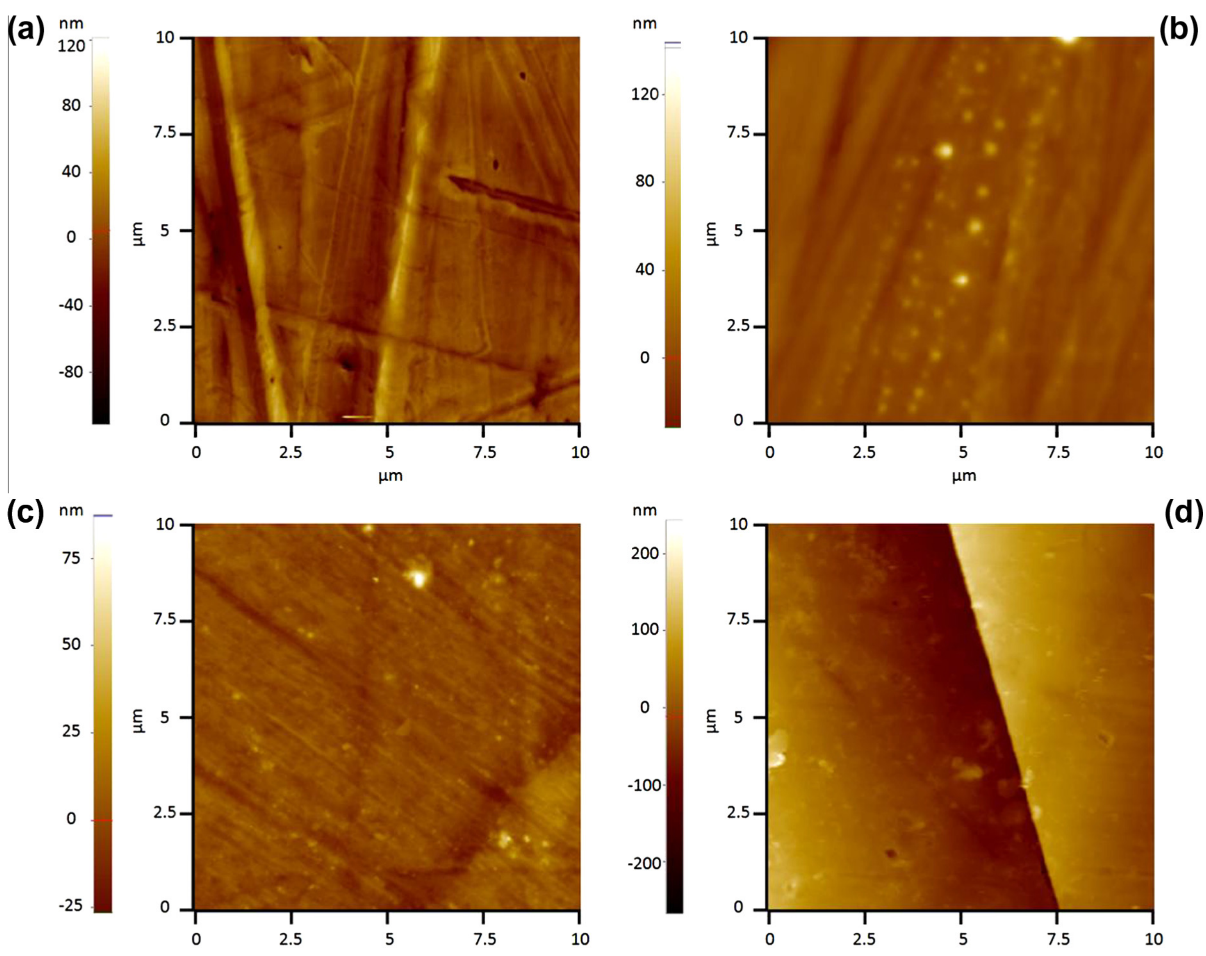

Fig. 2. AFM images of the (a) pristine PC and of the samples irradiated with (b) 1×10^{16} ions cm^{-2}, (c) 5×10^{16} ions cm^{-2}, (d) 1×10^{17} ions cm^{-2}.